The WIYN One Degree Imager: An Overview

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View from the 4 meter telescope

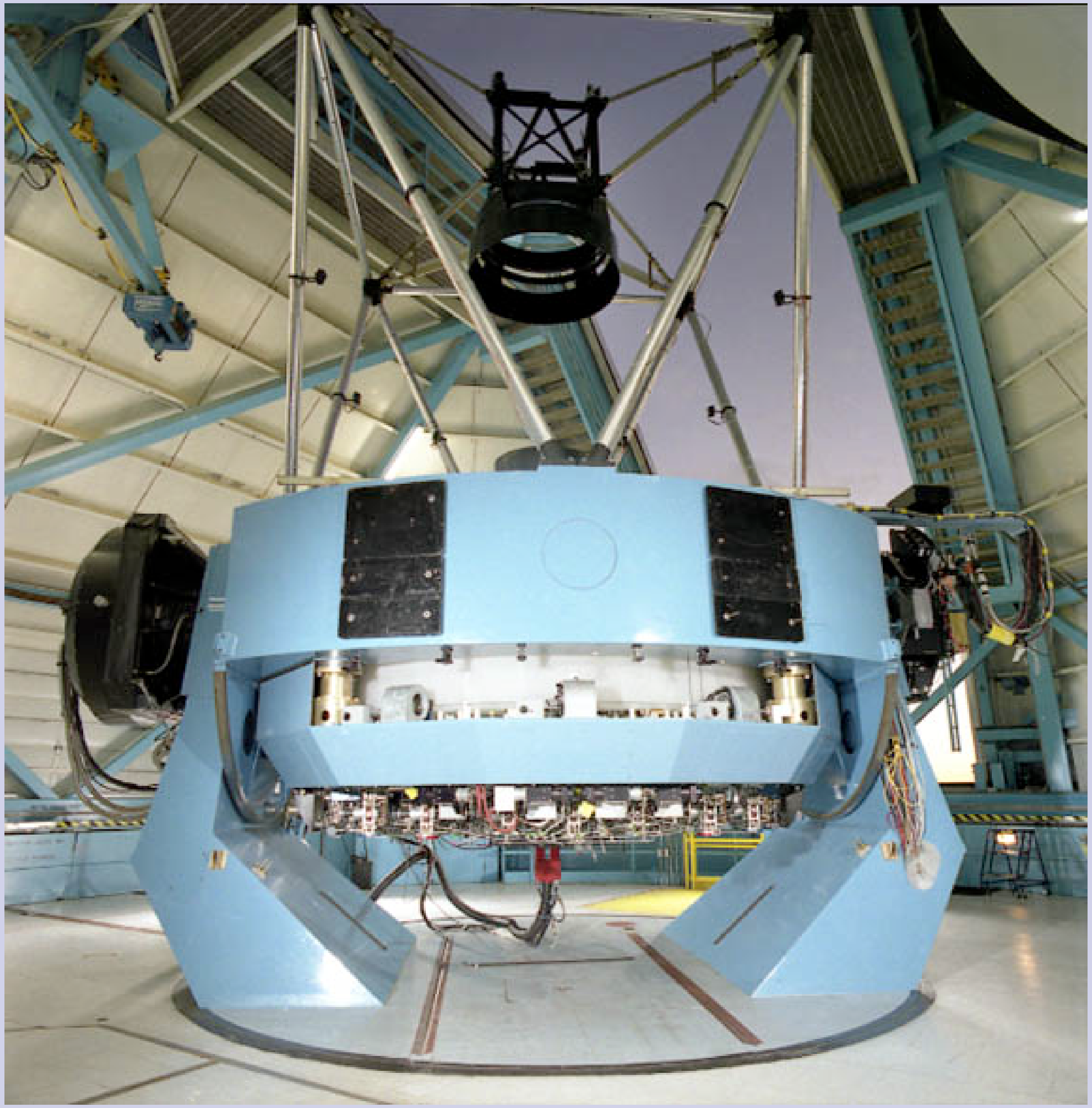
- WIYN Consortium, telescope built in 1995:
  - University of **W**isconsin, Madison (26%)
  - **I**ndiana University , Bloomington (17%),
  - **Y**ale, New Haven (17%)
  - **N**ational Optical Astronomy Observatory (40%)

WIYN: A modern telescope

- Optimized for image quality
  - active primary mirror support
  - careful thermal design
  - excellent optics

- 1º circular unvignetted field of view

- DIQ is atmosphere limited.
  - seeing of 0.35” on z’- and U-band science exposures reported.
  - Median seeing in R better than 0.7”.



Key Questions in Astronomy

- What is the nature of the Universe (Dark Energy) ?
- How do galaxies form and evolve (Dark Matter & Baryon interaction) ?
- How did the Galaxy form and evolve (Detailed study of baryons in a DM halo)?
- How do stars form and evolve (The first stars and early enrichment)?

Finding Answers

- Large Scale structure in the Universe (many degrees).
- Structure of Galaxy Clusters (a few degrees)
- Weak and strong lensing (a few degrees)
- Structure of galaxies (sub-arcsecond for large z, but large samples)
- Structure of the Galactic halo (entire sky)
- Very rare objects (Extremely metal-poor stars, interacting binaries, ...)

- The astronomical community is building a plethora of new wide field imagers:
  - Skymapper, VST, VISTA, DECam, **ODI**, PanSTARRS, LSST, Hyper-SuprimeCam, ...

A One Degree Imager for WIYN

- Use WIYN's 1º field of view.
- Utilize the excellent seeing of site & telescope.

- Further enhance image quality by active tip/tilt image motion compensation.
  - 20 Hz guide loop speed required, 50Hz goal.
  - Shown to improve median seeing in R by 0.15".

- Median DIQ of ~0.55" in r', capability of DIQ < 0.3" design goals.

- Sample the focal plane with 0.11" pixels -> 1GPixel camera.

- High observing efficiency, automated cadences:
  - shutter close to open <<20 sec in snapshot mode

- Provide on-site basic data reduction
  - Instrumental detrending, meta data, WCS...

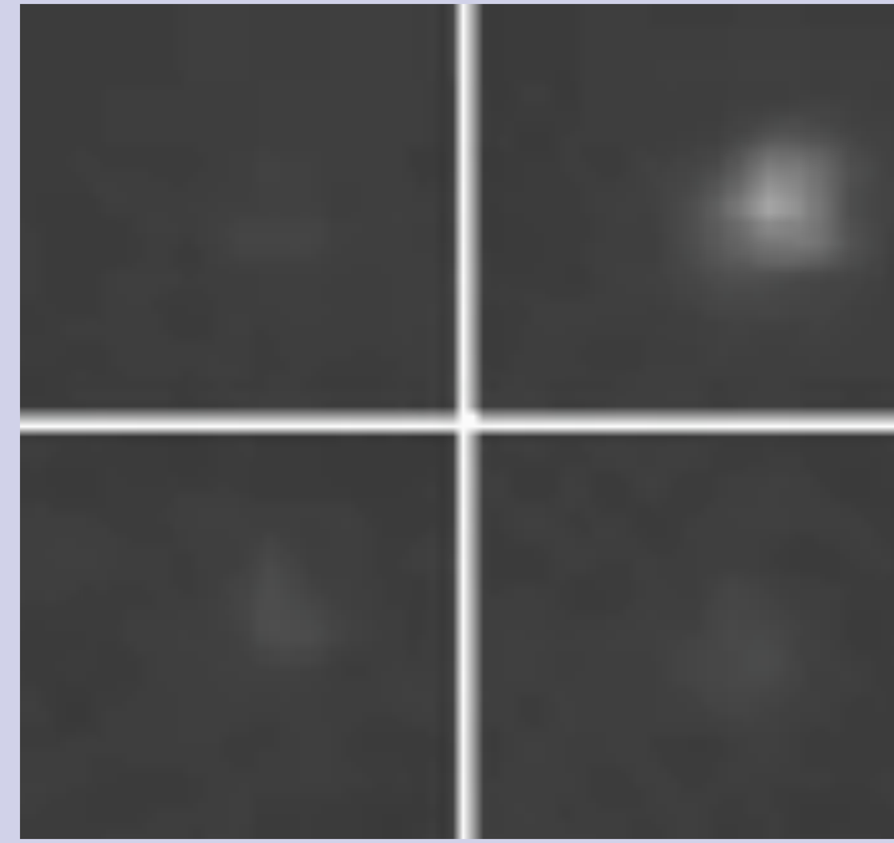
Effect of Tip/Tilt motion on image quality

- Atmospheric turbulence, wind-shake cause image motion

- Some image motion is correlated, e.g., due to telescope shake
- Uncorrelated image motion due to atmospheric turbulence

- (Not too new) Idea:
  sense motion from a bright guide star and compensate for it
  - Active secondary mirror (common in AO systems)
  - Move detector (consumer digital cameras)
  - Move electrons in detector (Orthogonal Transfer CCD)

- **New Idea: do it over 1º FoV**



ODI’s Technical Motivation: High Image Quality Over 1°

- WIYN has excellent native seeing (median ~0.7” in R)
- WIYN has a 1º field of view
- Tip/Tilt performance at WIYN
  - Improves seeing by ~0.14” in FWHM (typical in R)
  - r’, i’, z’ medians become ~0.54”, 0.43”, 0.35”
  - *But*, at 2 arcmin radius, atmosphere decorrelates: degrades 0.32” images by 10%
- Magnitude limit ~14.5mag.

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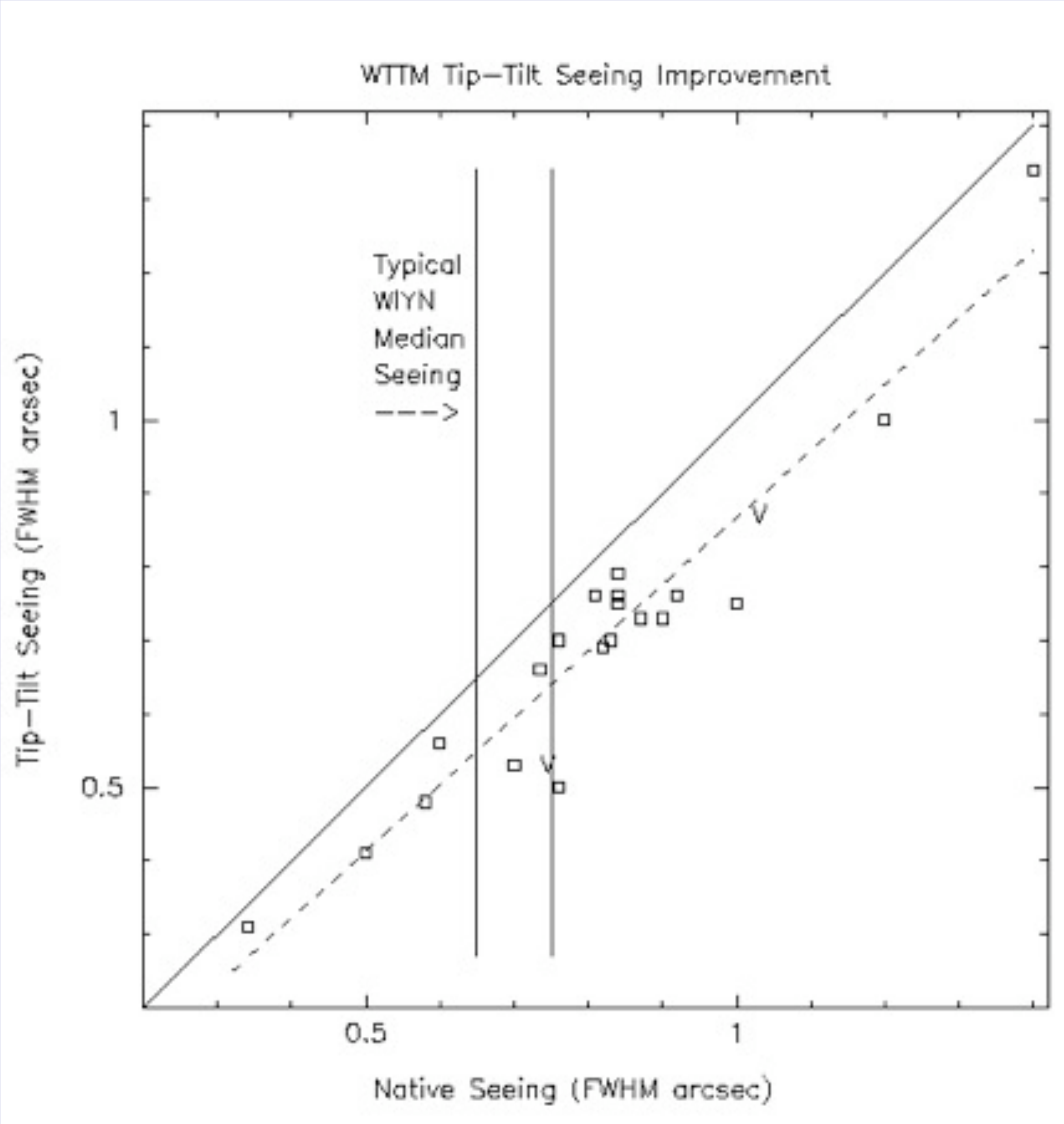

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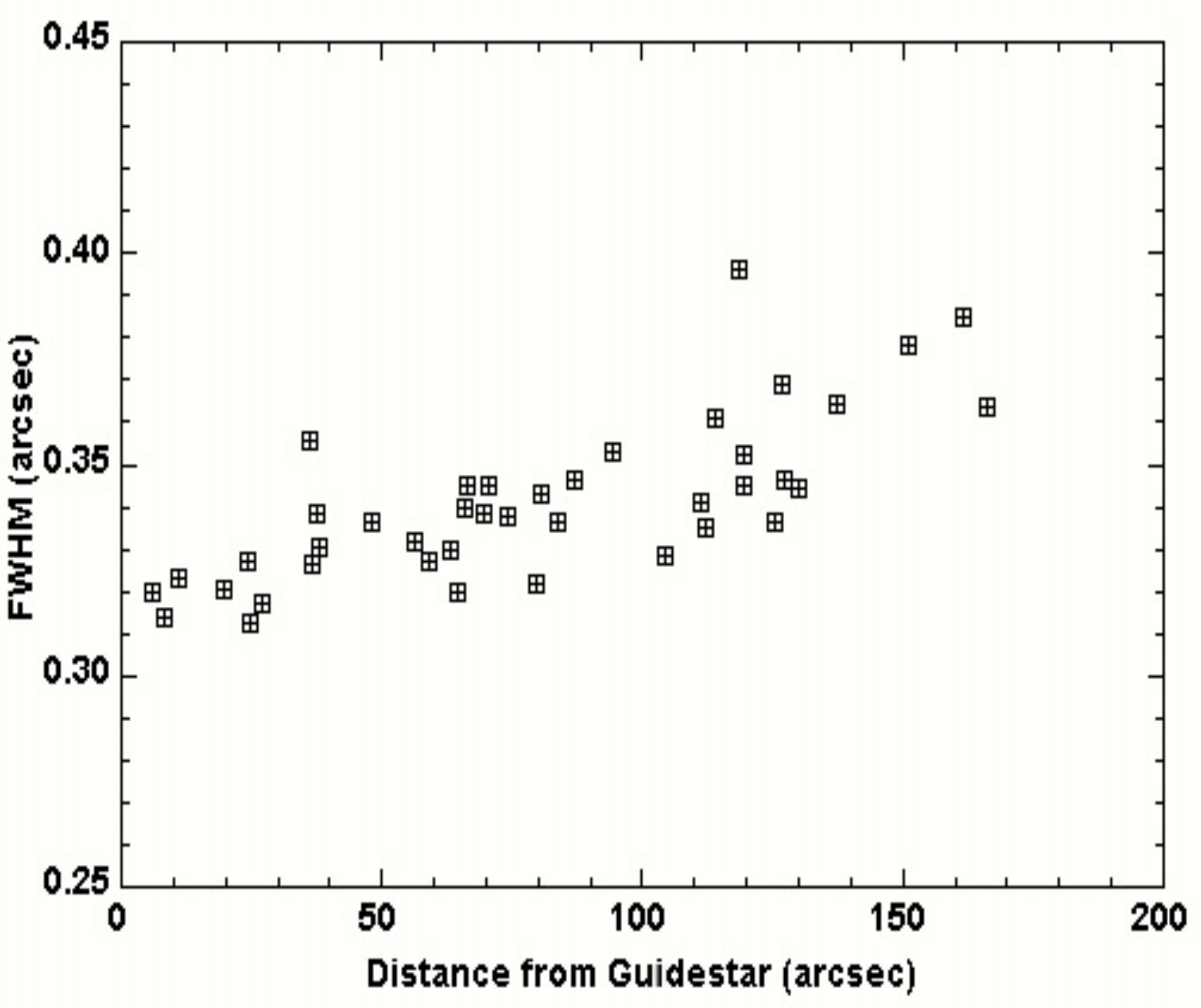
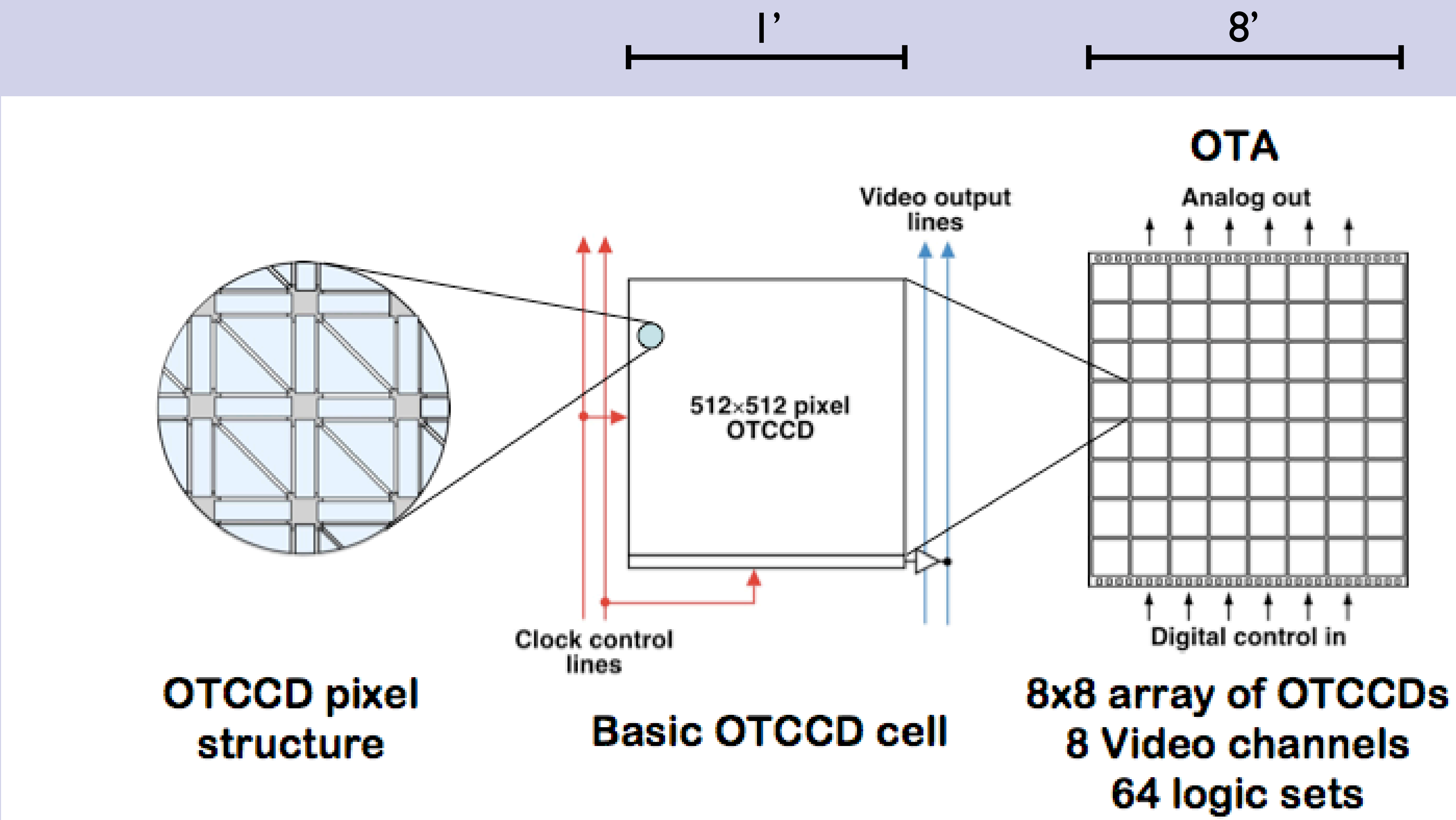


Orthogonal Transfer Array CCD



each cell is an independent CCD ~1' on sky

each cell can be read out in video mode

each cell is either imaging or obtaining guiding information at up to 30Hz

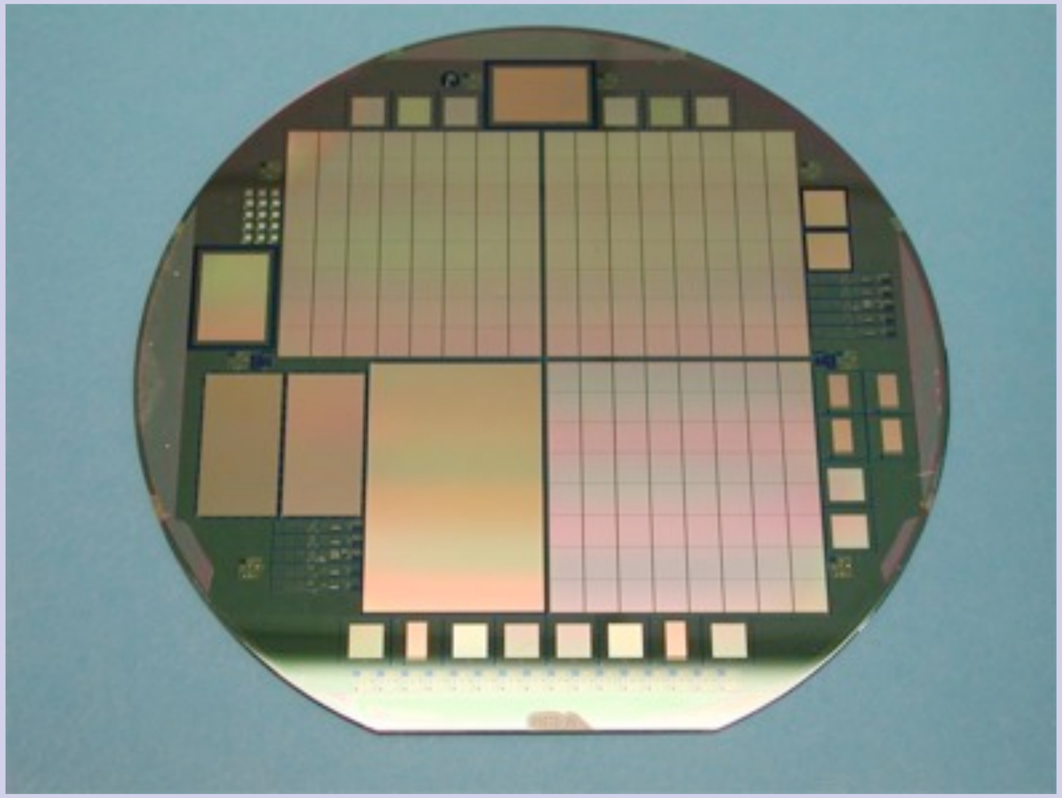
tip/tilt correction can be applied to each individual cell

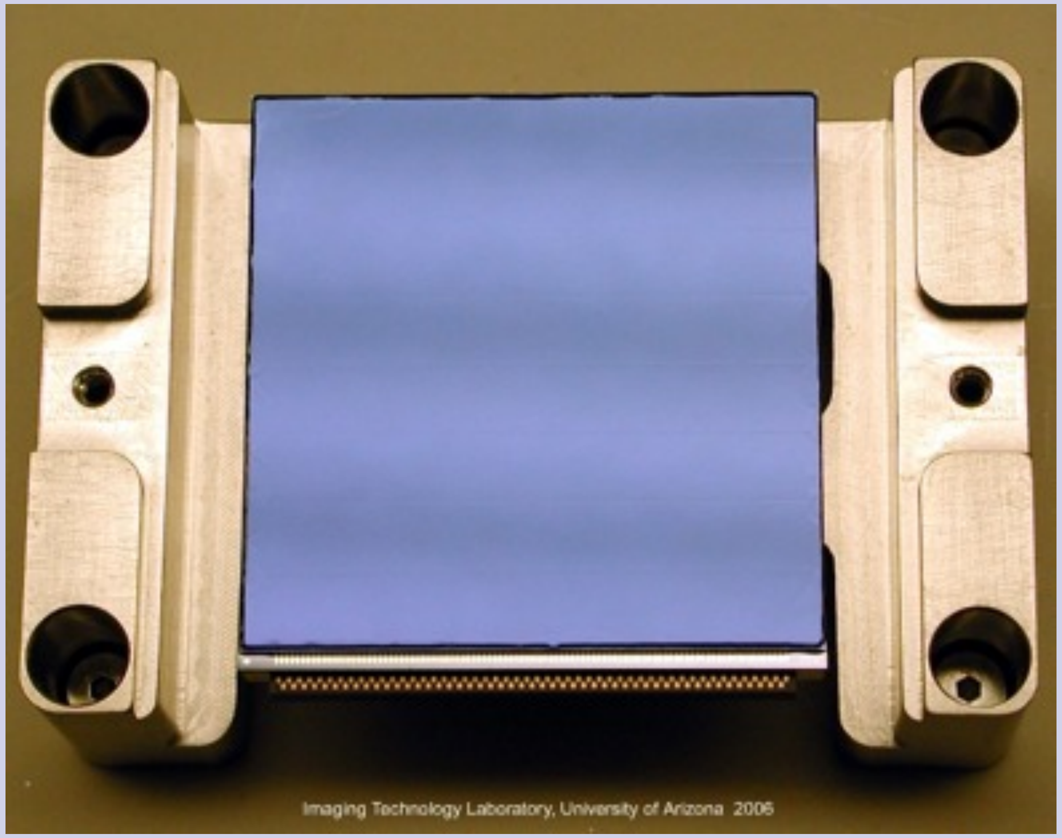
OTA Detector Development

- OT(A) concept invented by John Tonry (IfA)
- Collaborative development of OTAs w/ PanSTARRS project

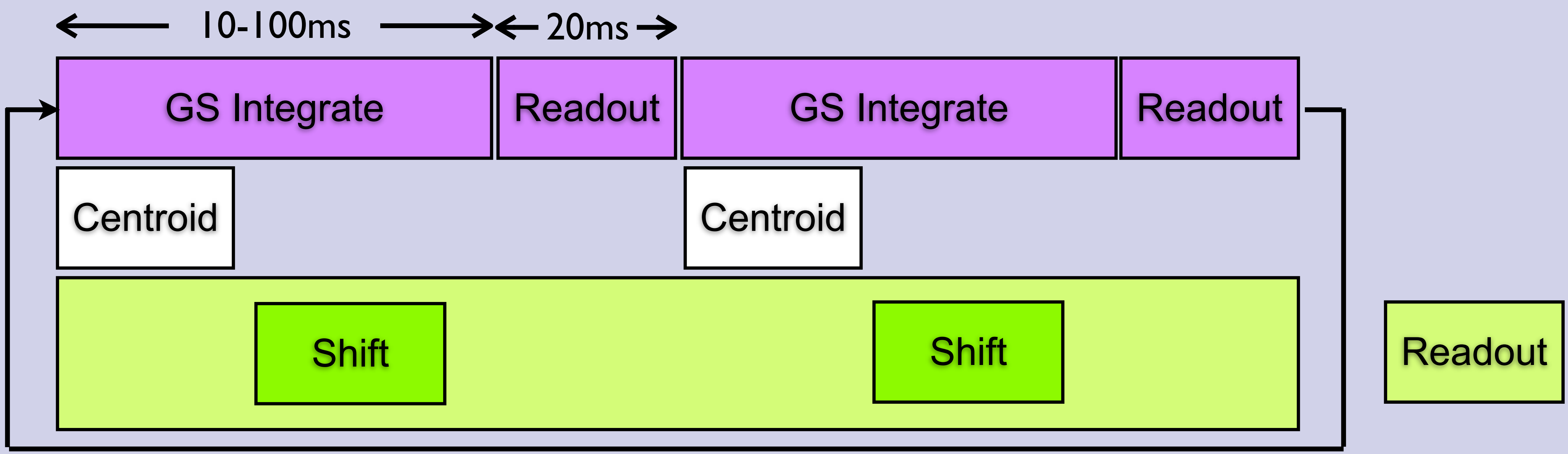
- ODI works with STA/DALSA
- Wafer production complete.

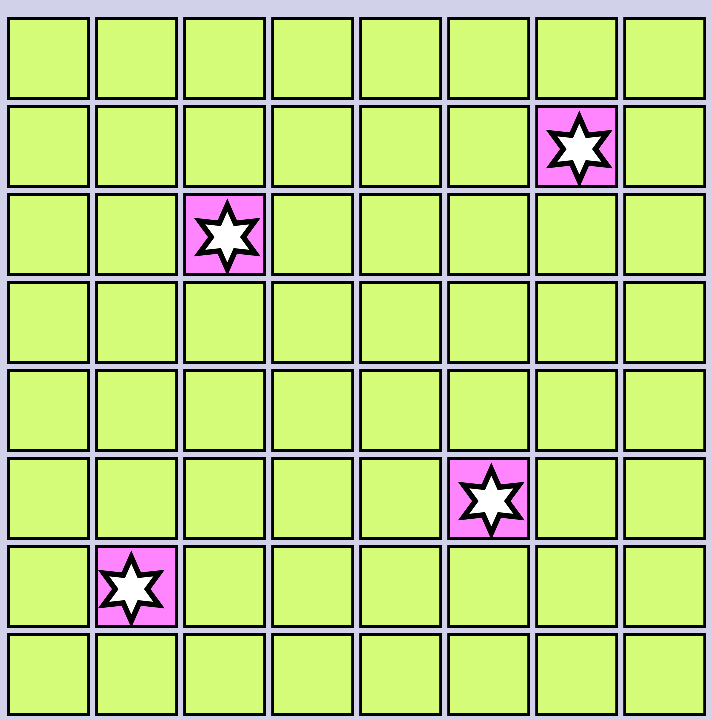
- Processing of wafers done by ITL (University of Arizona)
  - Thinning, packaging, and testing
  - Mounting detectors on SiC focal plane





OTA fast tip/tilt guiding



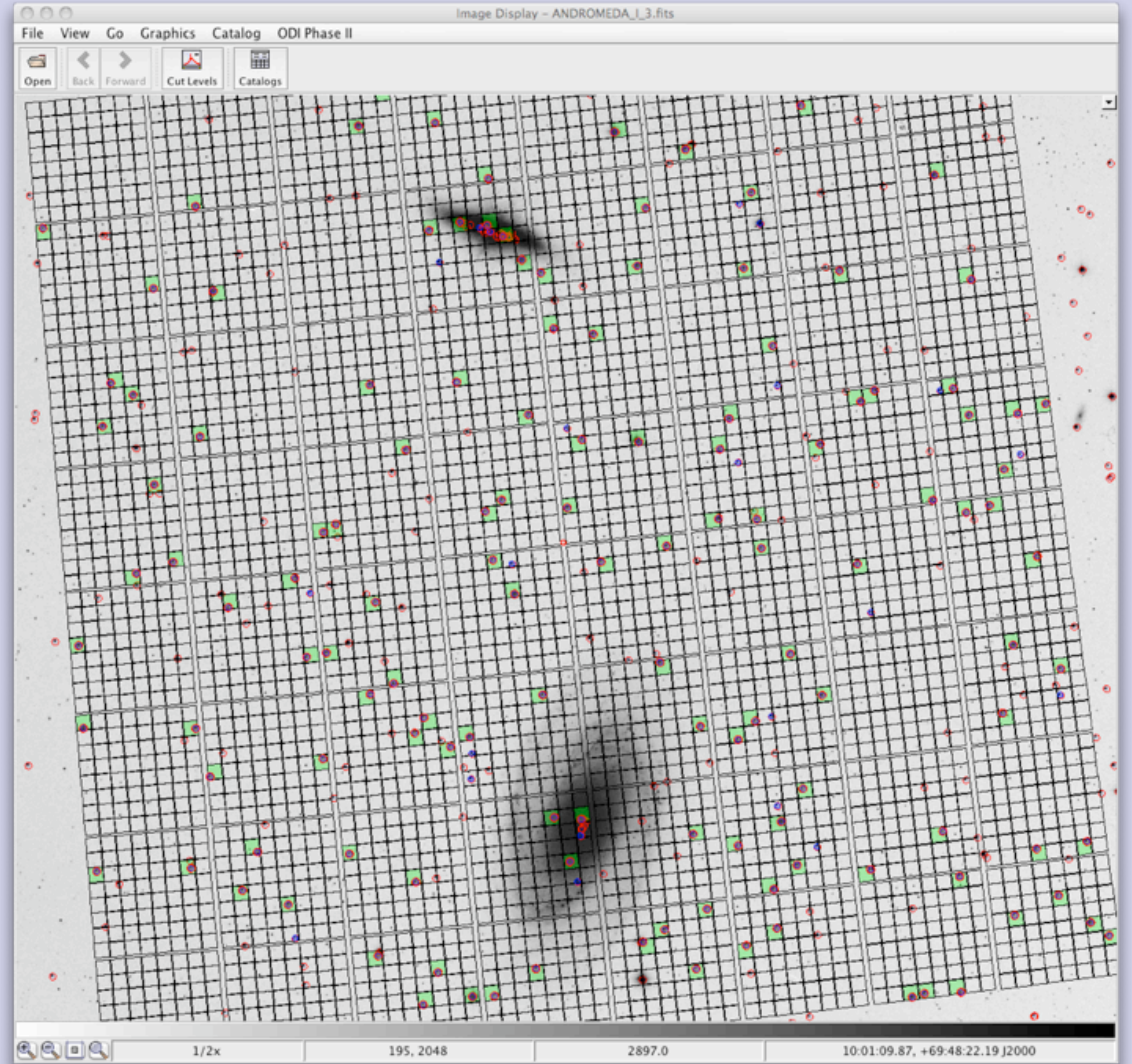


Weight of guide star *i* on cell *j*:

$$\delta\vec{x}_j = \frac{\sum {r_{ij}}^{-n} \cdot \delta\vec{x}_i}{\sum {r_{ij}}^{-n}}$$

n=0 equal weight, common mode only
n=1..2 distance weighted
n=large nearest neighbour

... on a 1º Field of View

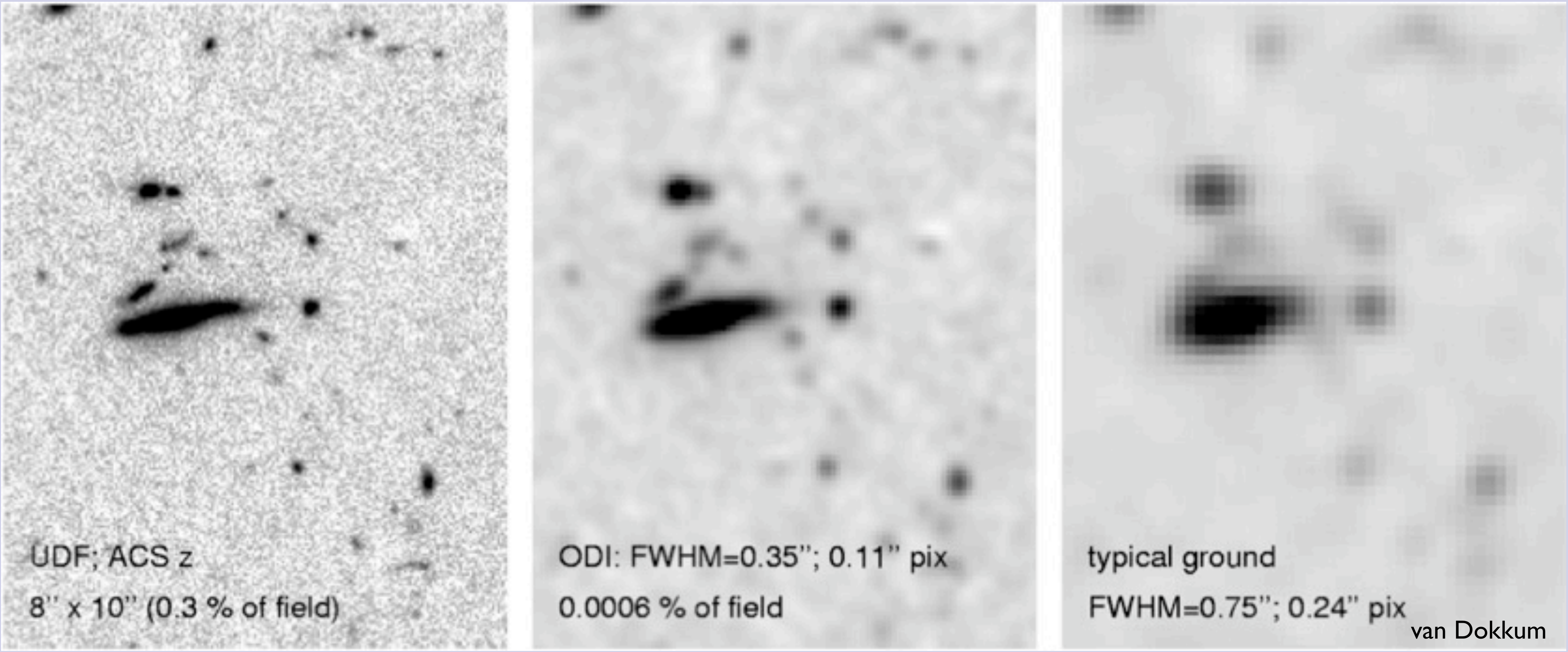


OTA Operational Modes

- Static Imaging
  - Use focal plane as conventional imager.
- Coherent Guiding
  - Sample only a few guide stars (e.g., one in each corner).
  - Correct 1º field for common-mode image motion.
  - Removes guide error, wind shake.
- Local Guiding (default mode)
  - One guide star every 4 arcminutes; ~200 over 1º!!
  - Correct for atmospheric turbulence (tip/tilt only).
  - Correct in ~4'x4' cells only.
  - Not fully possible everywhere on sky.
- Targeted Photometry
  - Use guide star for shutterless photometry.
  - Select guide star for science goals (vs. to optimize guiding).
  - up to 512 guide stars.

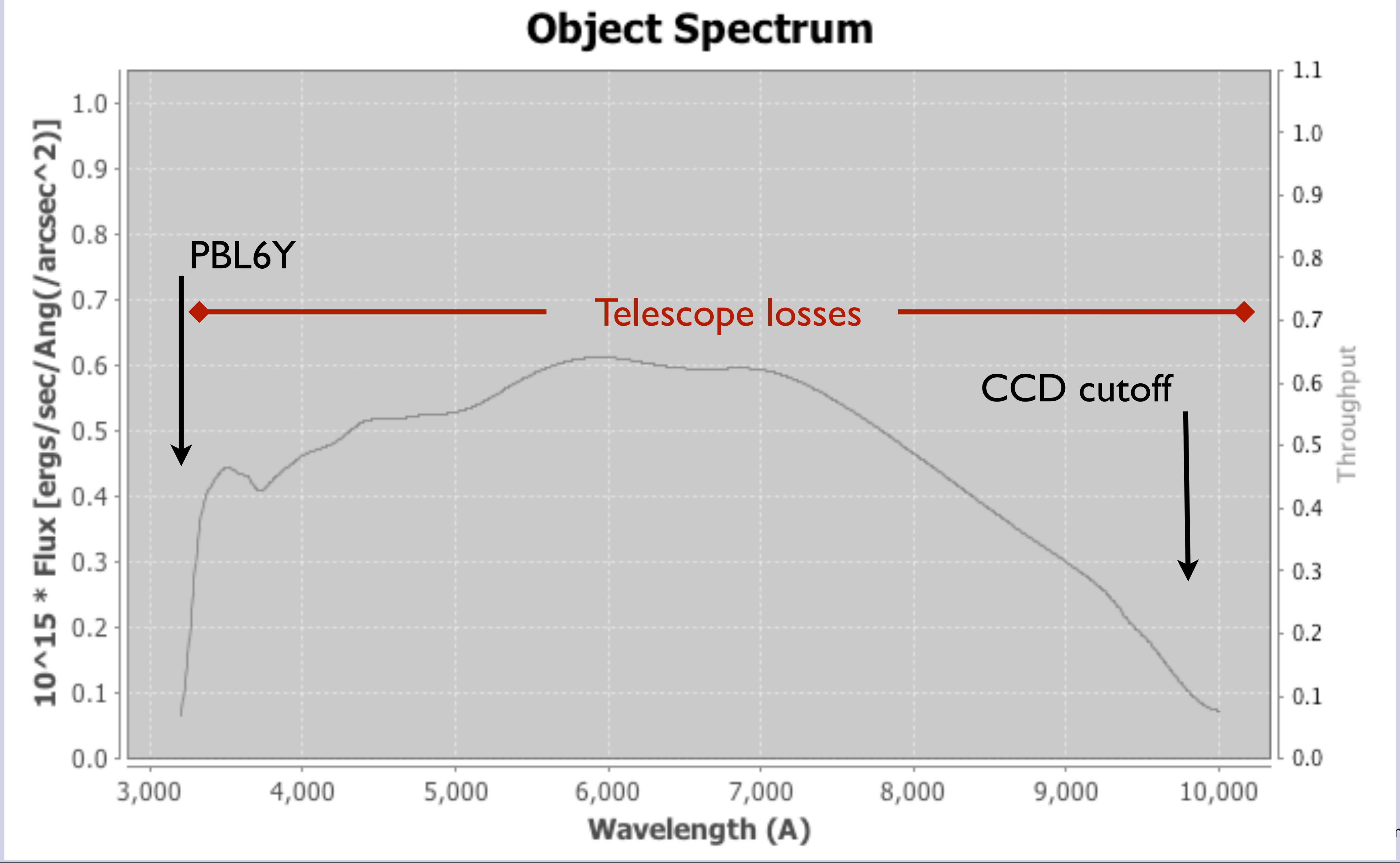
ODI's niche:

- High-resolution, wide-field imaging

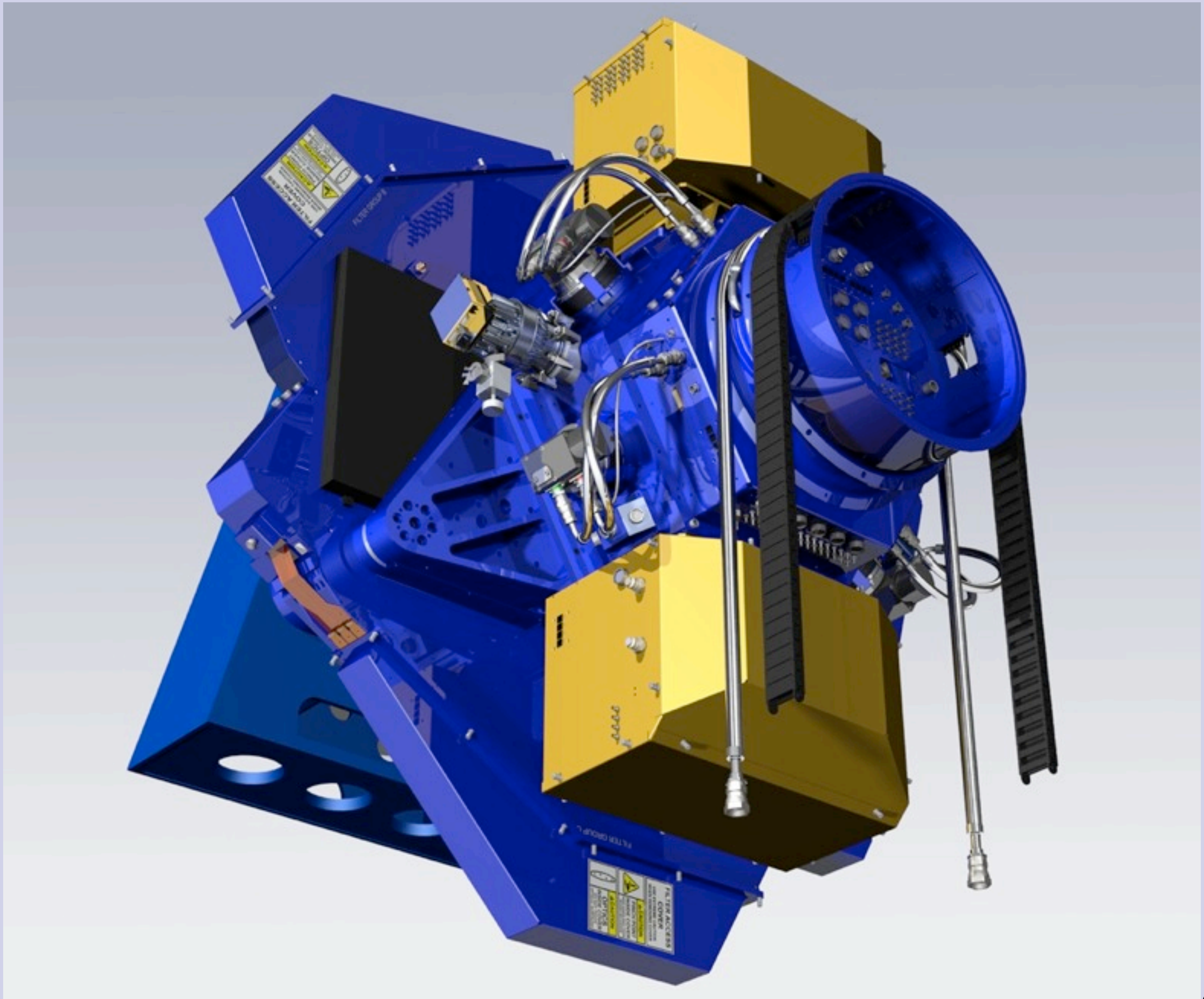


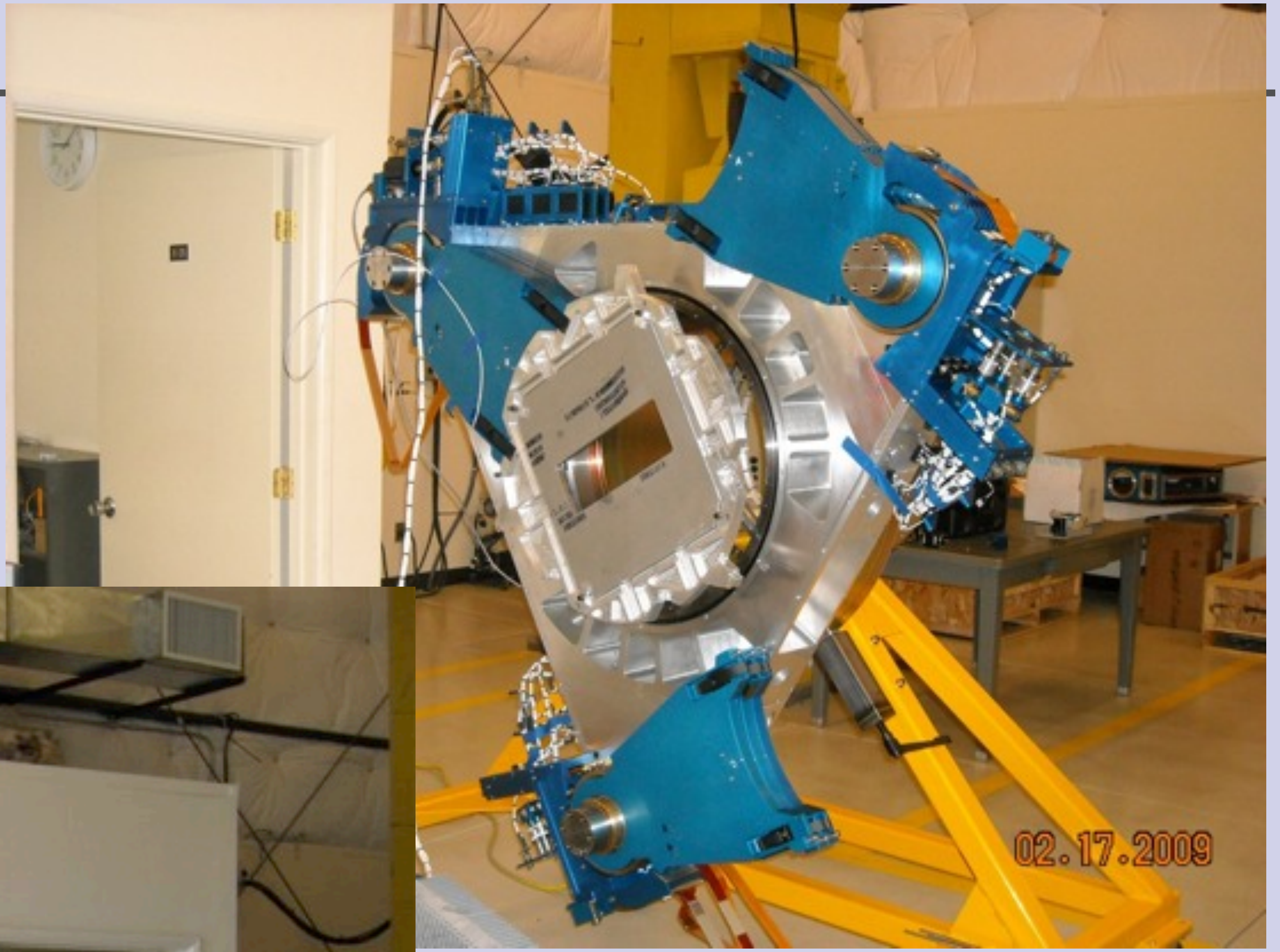
Expected Throughput

- 3x mirror reflections (Al coating)
- 8x reflection losses at optical surfaces (coatings, as built)
- PBL6Y, Fuse Silica
- CCD sensitivity



Key instrument components

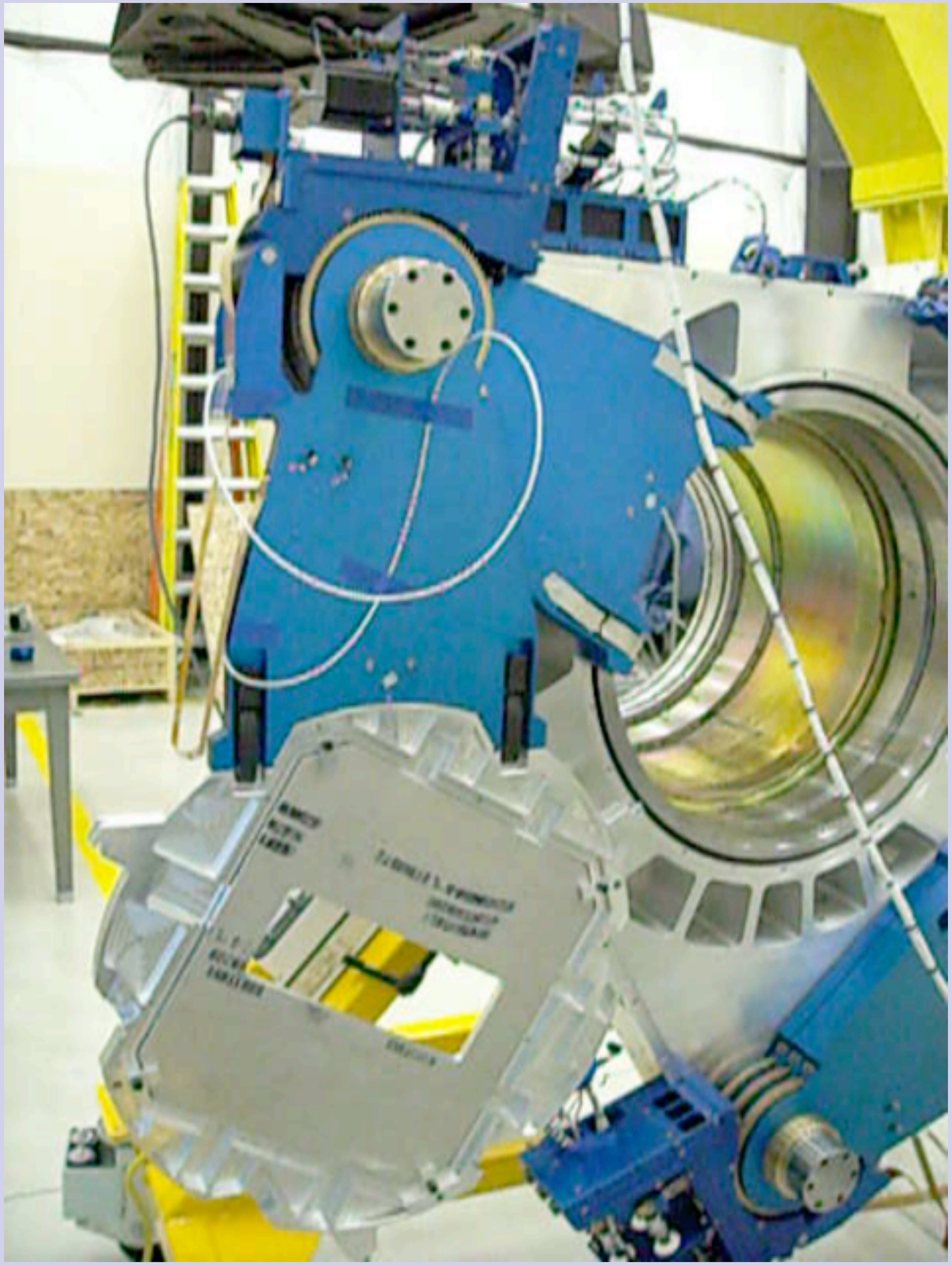



02.17.2009

Filter Mechanism

- Design challenge: filter size (42cm)
- Filter cost ($60k-$100k est.)
- Filter weight
- Safe handling
- Minimum of 8 live filters as requirements

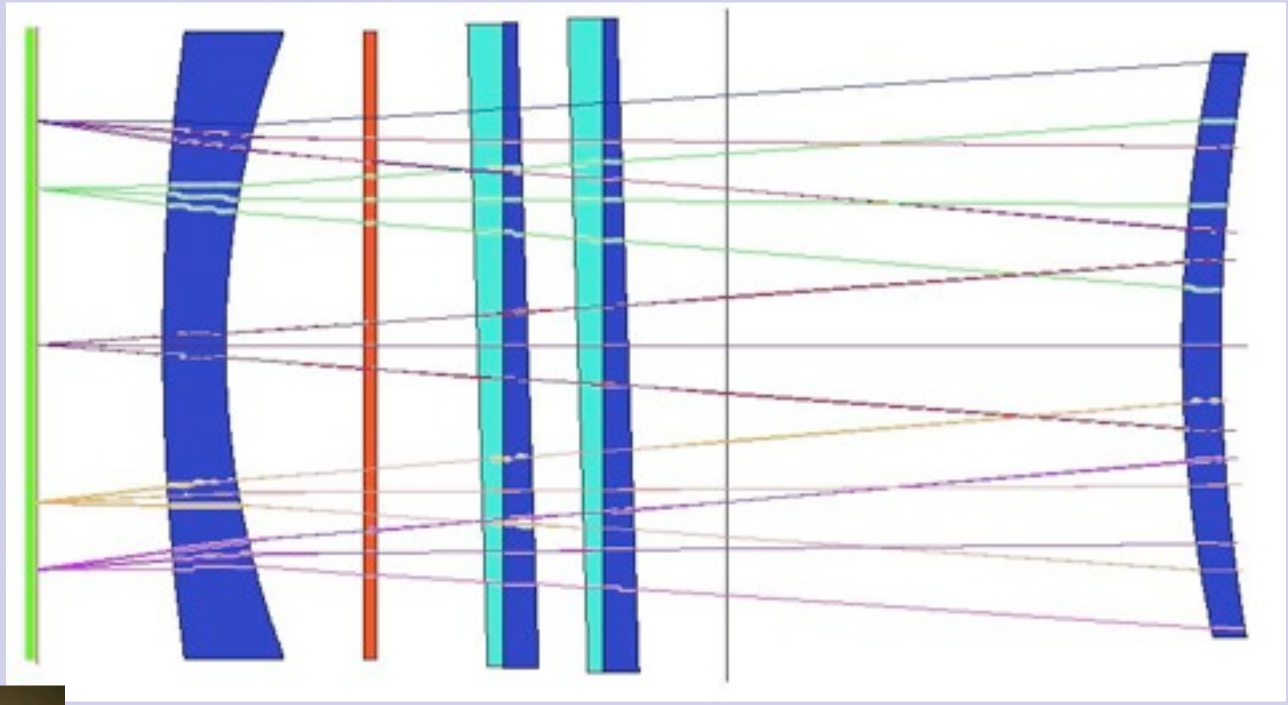
- ~30 seconds filter change time



Corrector Optics Design...

- Atmospheric Dispersion Compensator (ADC)
- less than 2% distortion over 1° FoV

- 2-element Design
- One aspheric surface

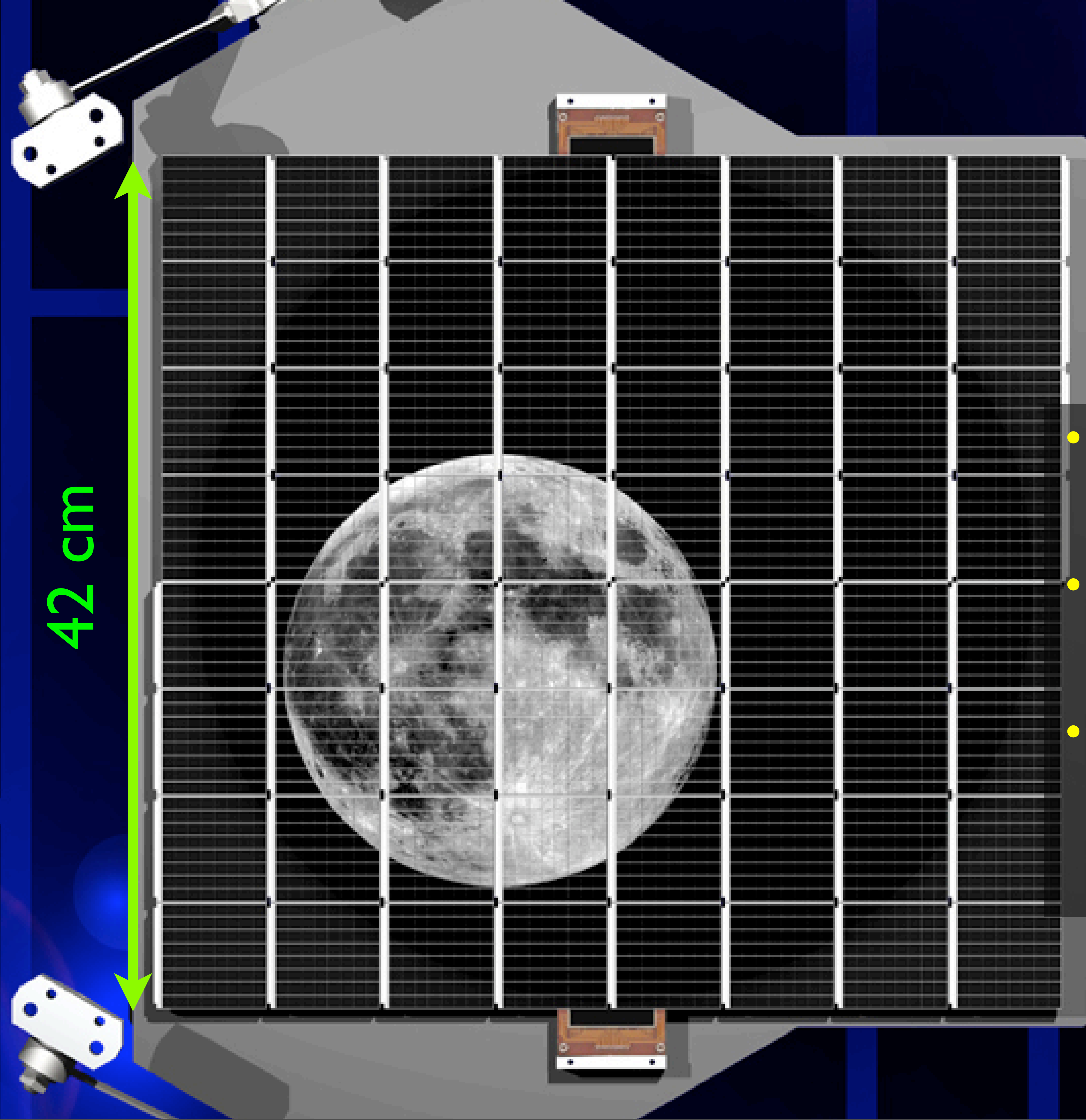


Production nearing completion @ SESO (France)

Shutter

- 2-blade design for accurate timing & short exposure times
- Designed and fabricated by the University of Bonn (Germany)
- Delivered and accepted.

Focal Plane



- Flatness Requirement most challenging
- Silicon Carbide as base-plate material
- Thinning, Packaging and mounting of focal plane contracted with ITL (Mike Lesser)


05.13.2009


05.18.2009
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3·8·6
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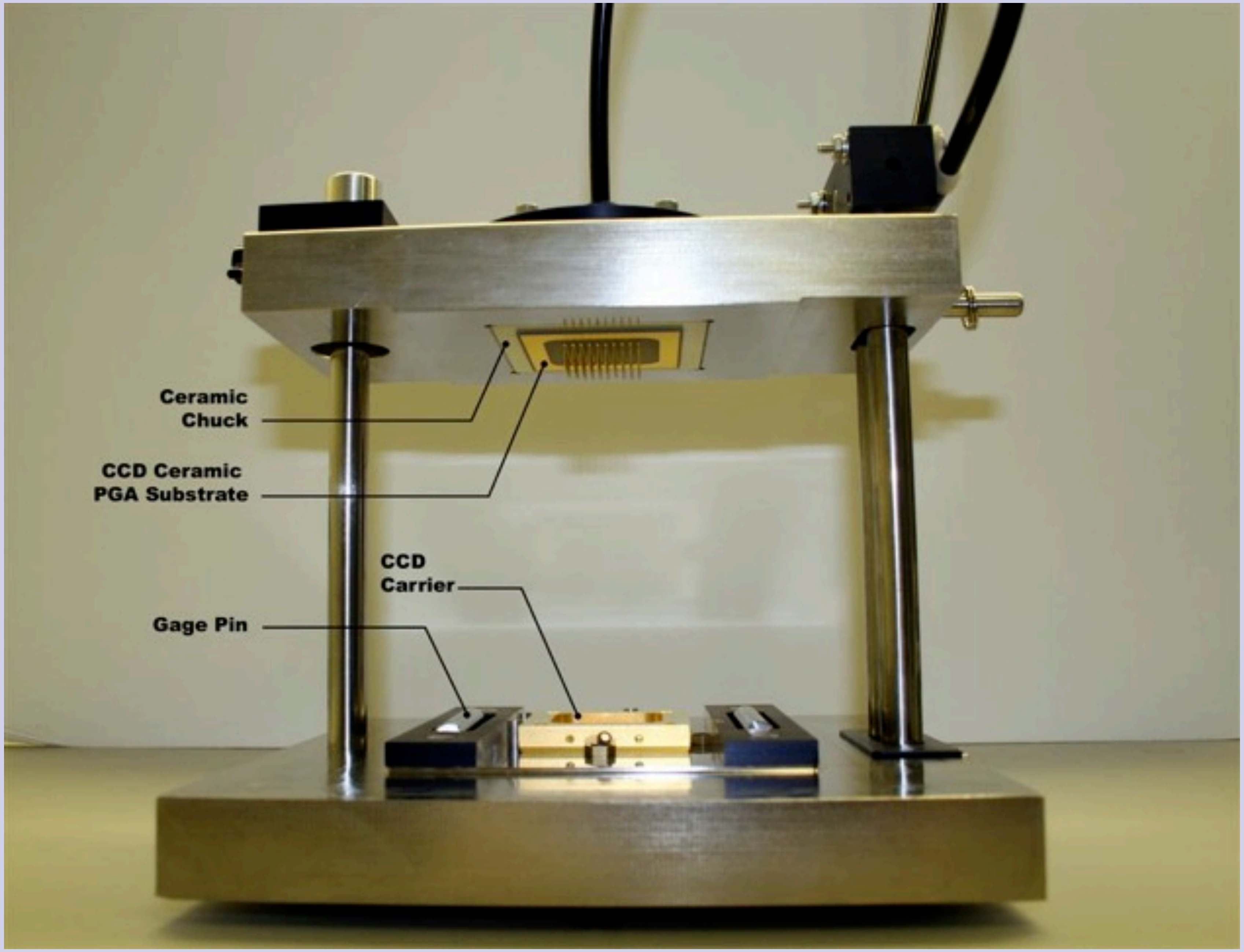
Detector Production

- Wafers completely produced.
- Now being thinned & packaged by ITL (Mike Lesser).
- Delivery of populated focal plane in January 2010.



Prototype Camera QUOTA

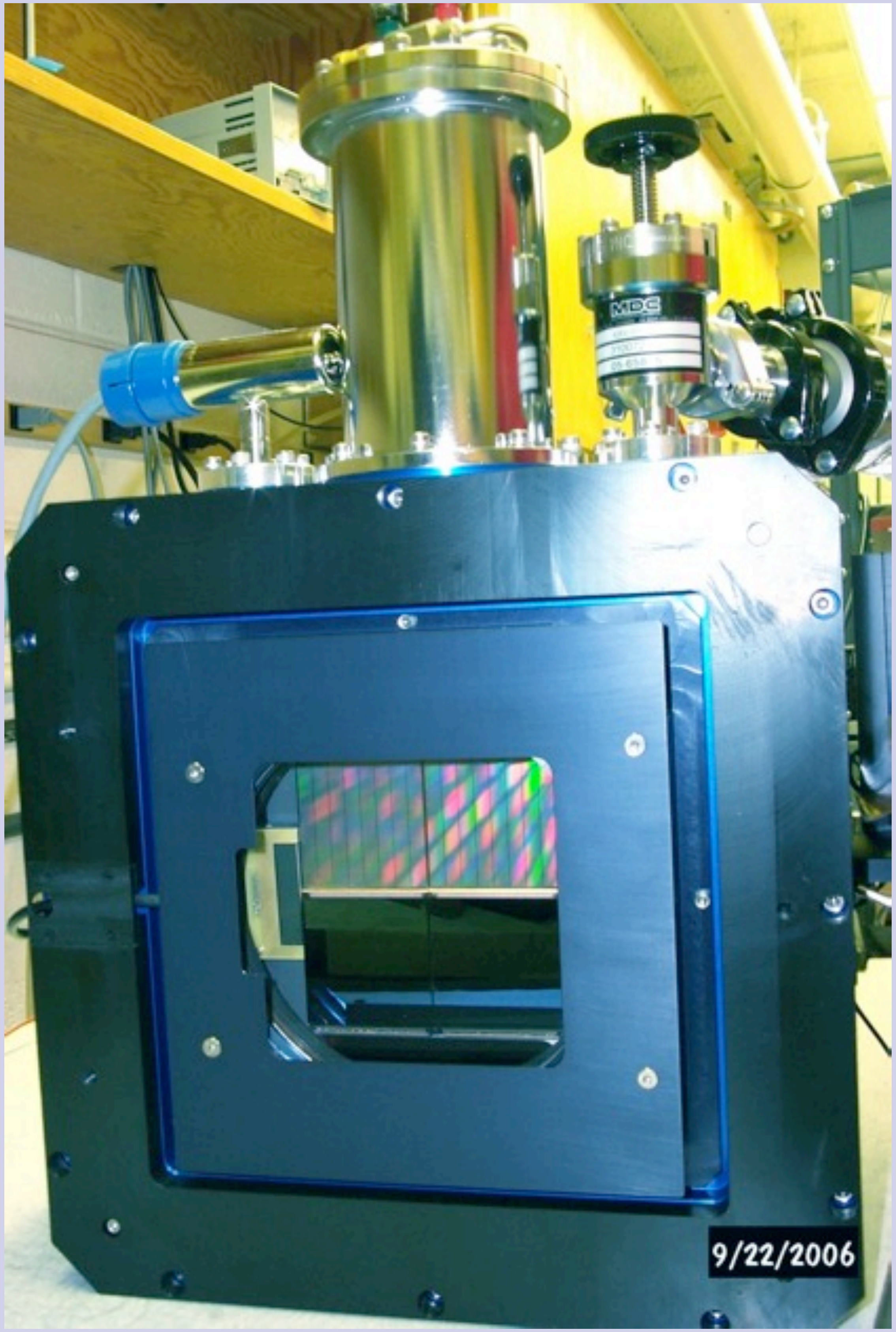
- Prototype camera to test OTA detectors
- Potentially for prototype science

- Several on-sky campaigns on sky
  - latest two weeks ago

- Demonstrated so far:
  - Detector operations
  - WIYN's image quality
  - On-chip guiding

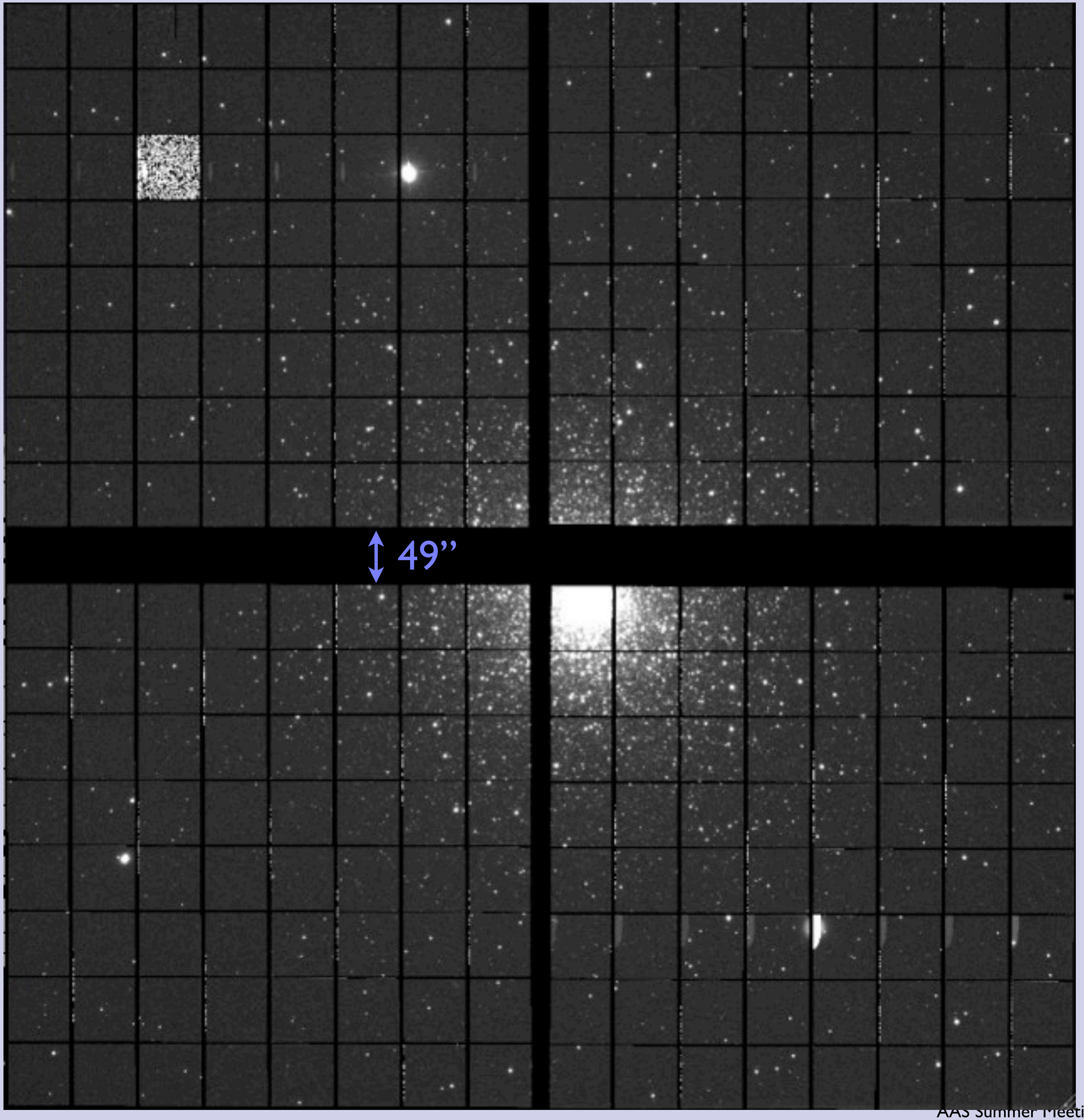
- Shown in 2006 configuration:
  - two thick, two thinned Lot 2 devices

- Current configuration:
  - four thick Lot 3 devices
  - one coated with Lumigen for blue response.



OTA Imaging w/ QUOTA

- M 15
- SDSS r'
- 120 sec



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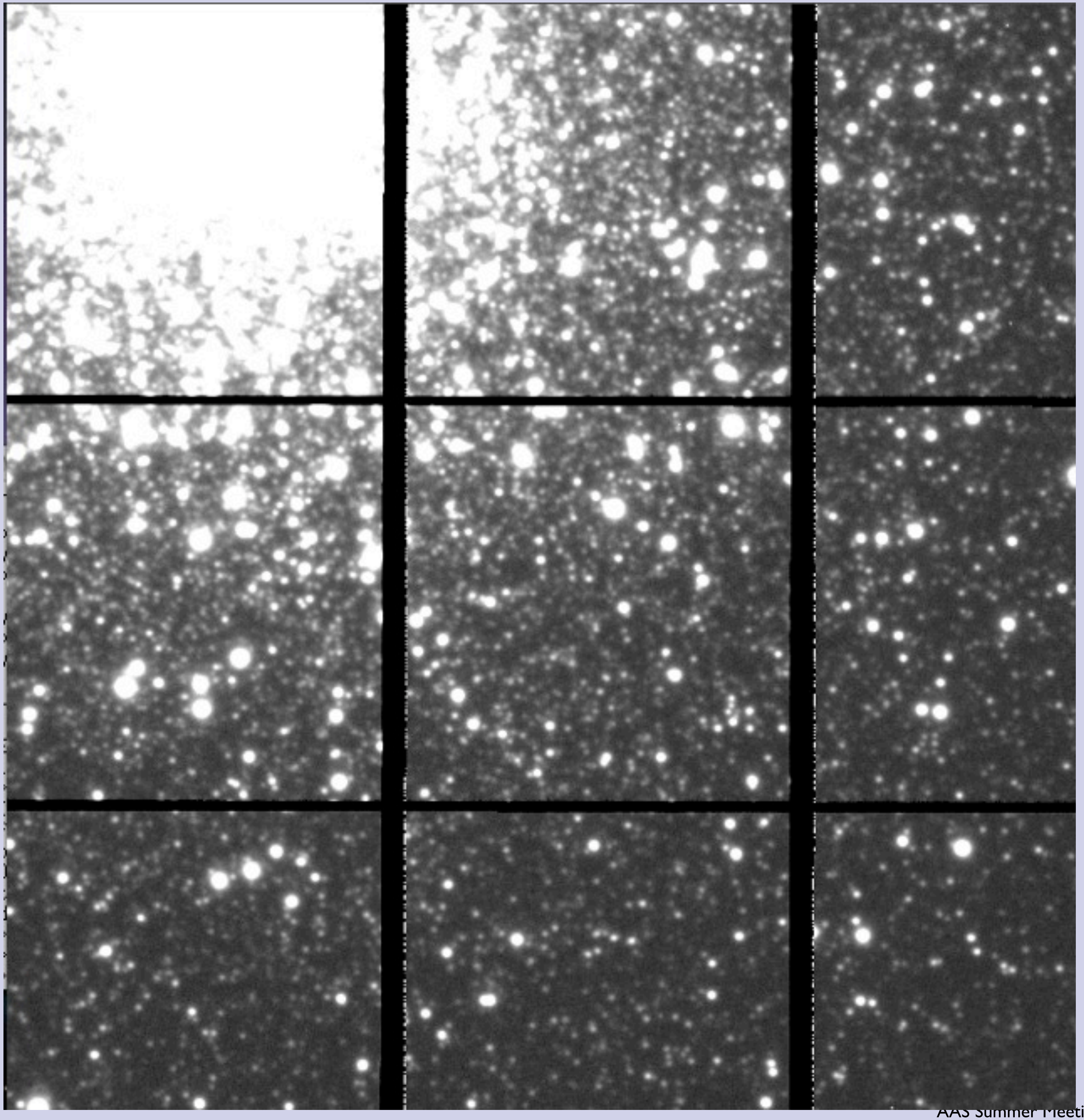
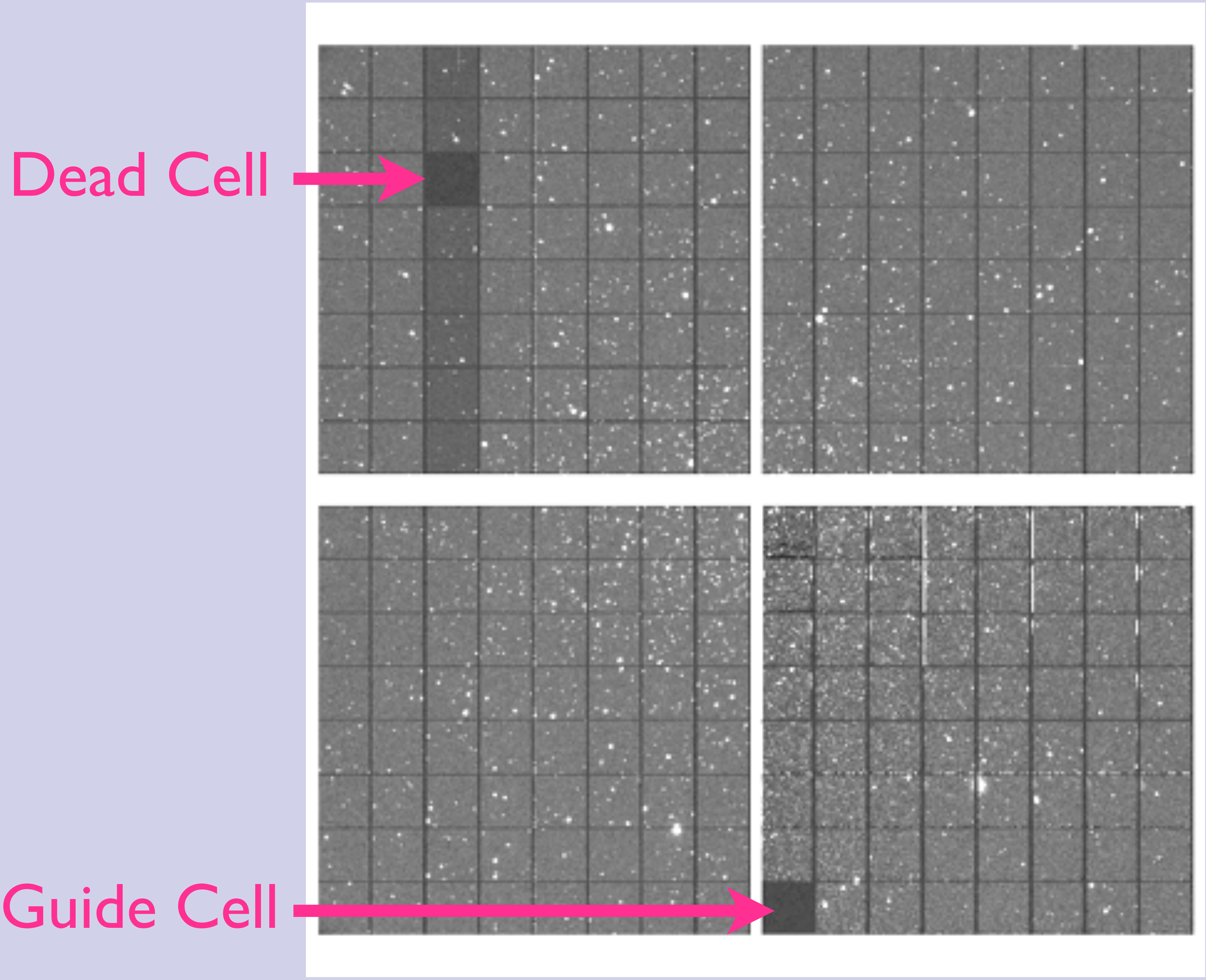
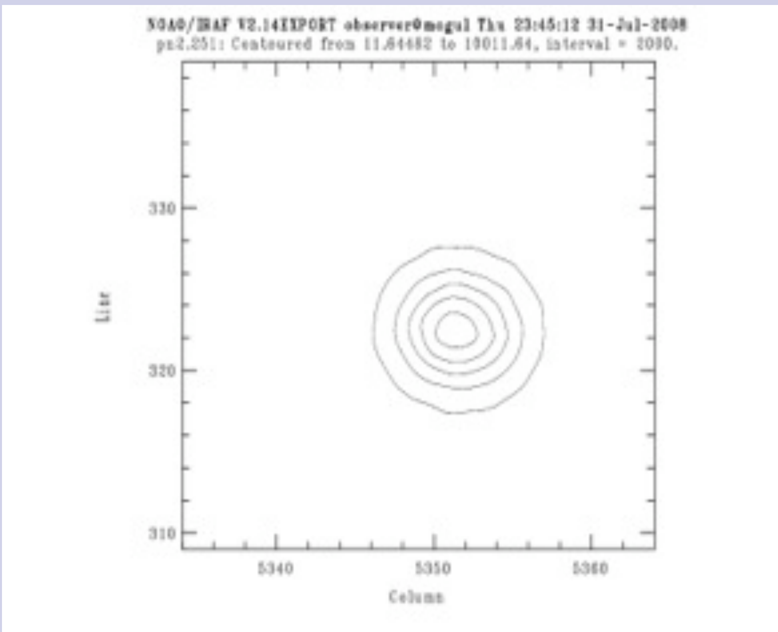
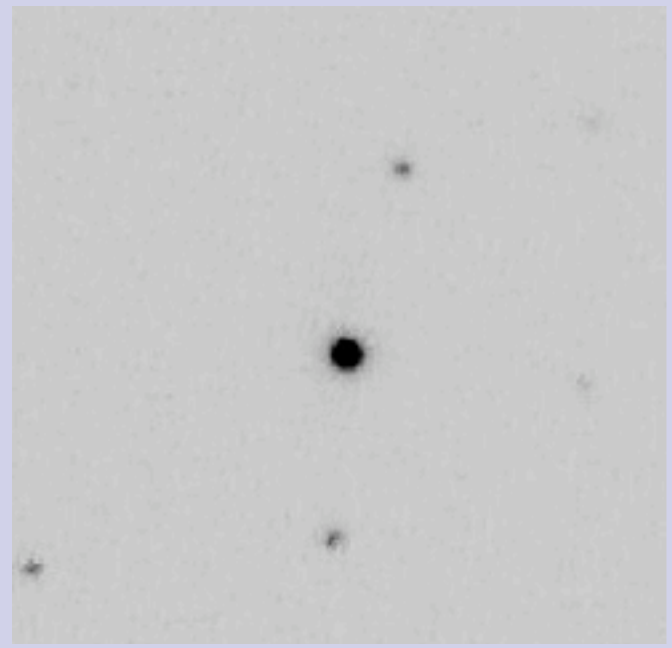


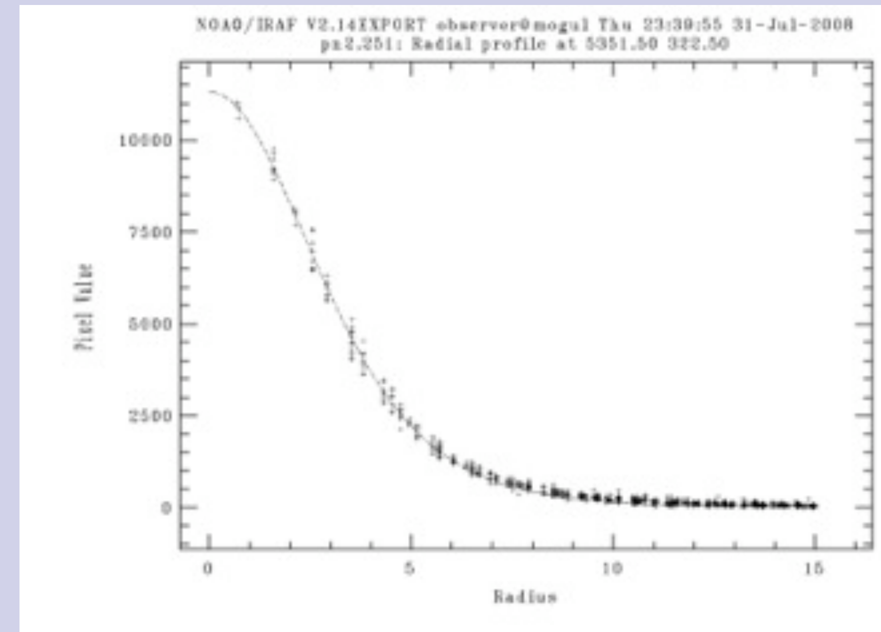
Open Cluster NGC 6791

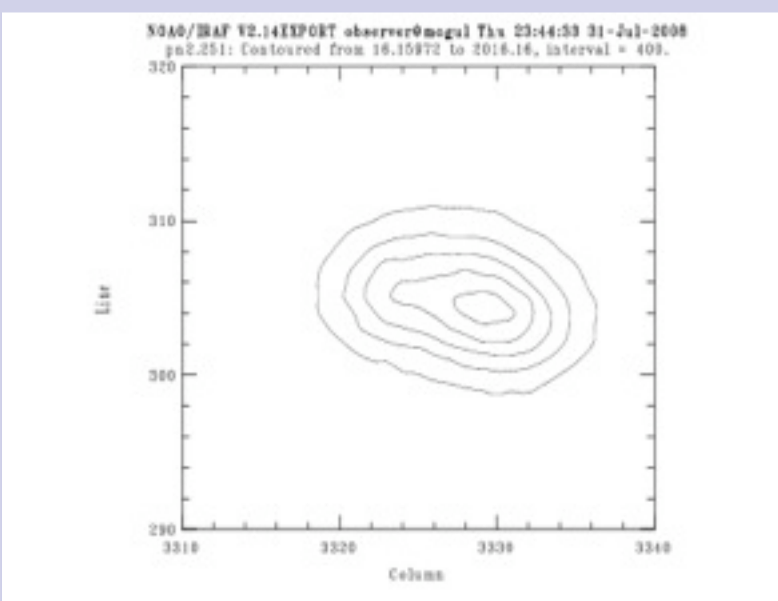


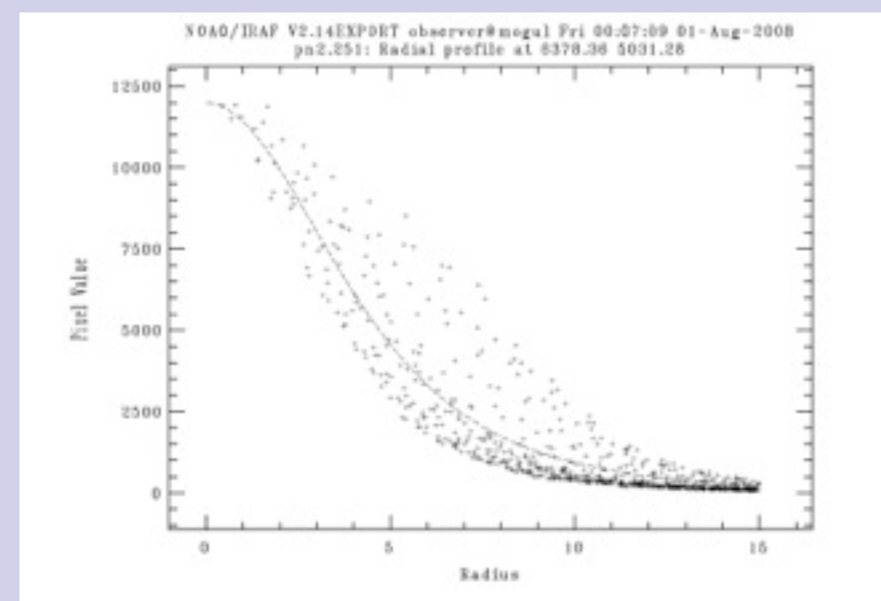
OT Image Improvement







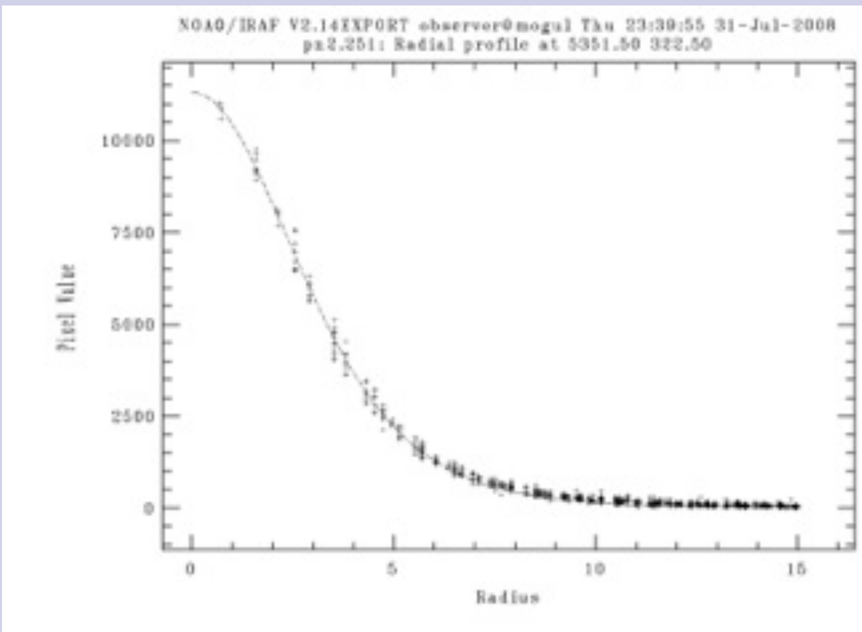




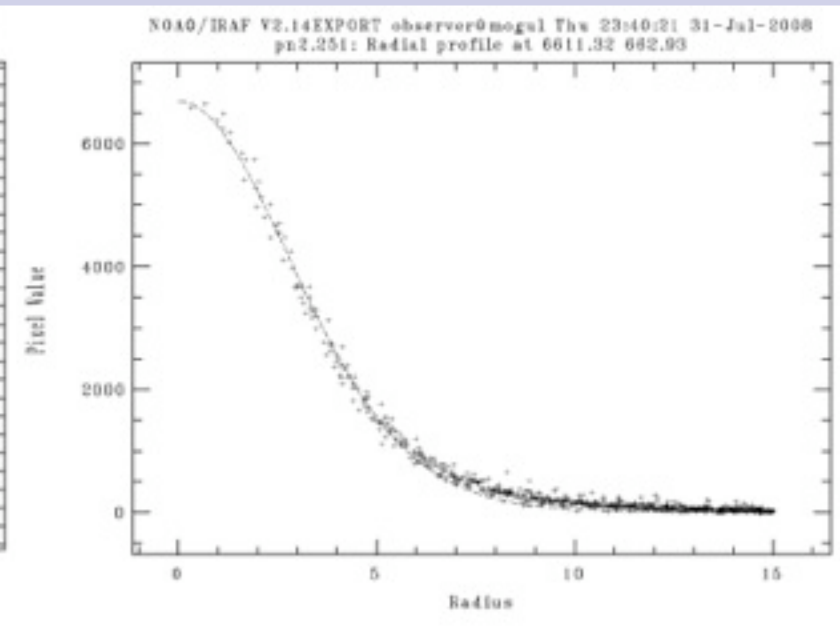
Guided Region - Top

Unguided Region - Bottom

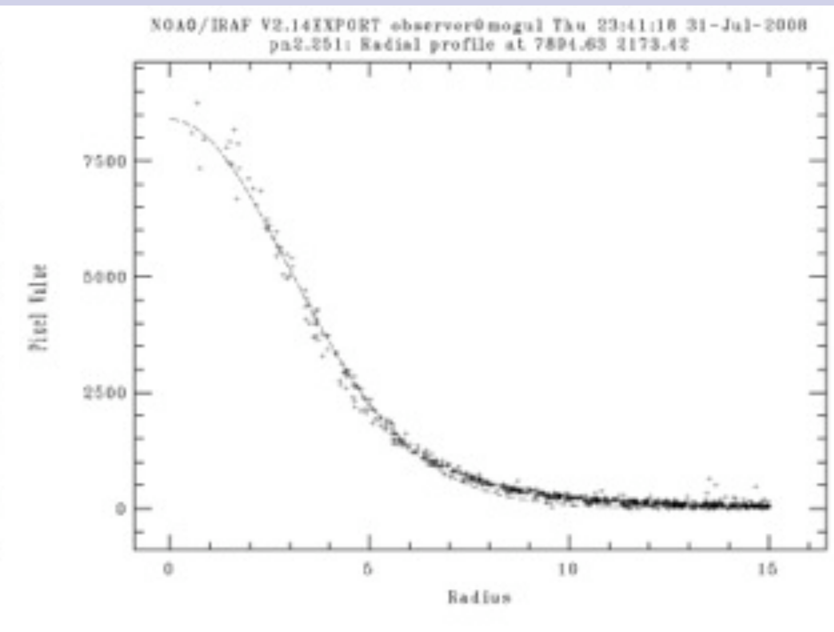
FWHM as function of distance from guide star



Distance: 2'
FWHM: 0.66"



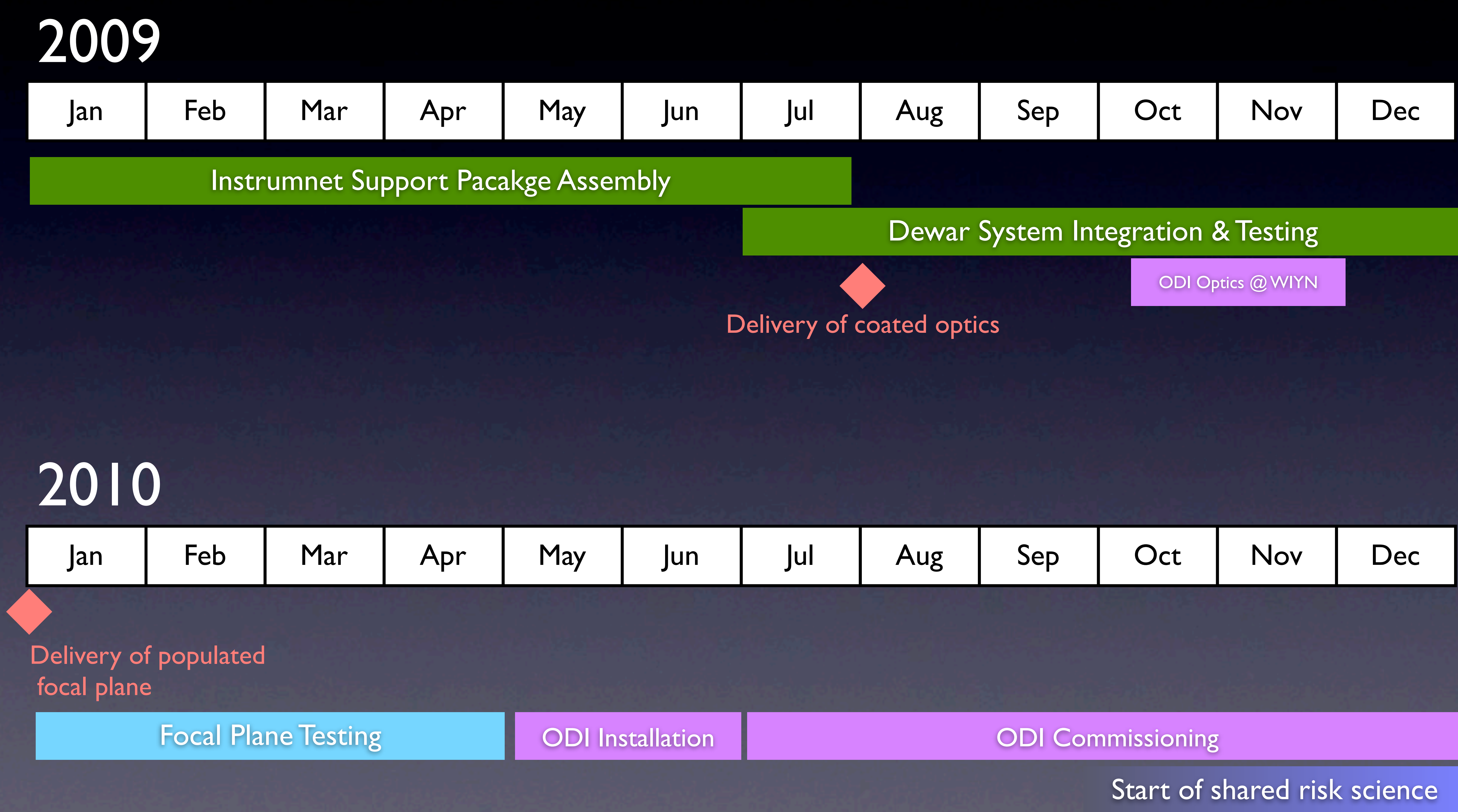
Distance: 4'
FWHM: 0.72"



Distance: 8'
FWHM: 0.78"


M51 seen by QUOTA:
• 50 min in U, 0.4" seeing
• 15 min in Y (red end of z')
• demonstration of sensitivity and image quality
• also demonstration of fringe behaviour

ODI Assembly and Integration Time Line




www.wiyn.org/ODI

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Bonus Tracks

Availability of guide stars

- At least one guide star available per chip on whole sky.
- Pointing needs optimization!
- If very few guide stars are available, correct for correlated image motion only